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Nucleon form factors program with SBS at JLAB

Bogdan Wojtsekhowski

*Thomas Jefferson National Accelerator Facility
 Newport News, Virginia 23606 USA*

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The physics of the nucleon form factors is a fundamental part of the Jefferson Laboratory program. We review the achievements of the 6-GeV era and the program with the 12-GeV beam with the SBS spectrometer in Hall A, with a focus on the nucleon ground state properties.

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1. The high Q^2 nucleon form factor experiments

The nucleon structure investigation using high energy electron scattering has been a successful field where many discoveries have been made since the 1956 observation of the proton form factor¹. To a large extent, this success has been due to the dominance of the one-photon exchange mechanism of electron scattering, which allows reliable interpretation of the experimental data². By the early 90s, the form factor data sets for the proton and the neutron were found to be mainly proportional to the one form factor, $F_{Dipole} = (1 + Q^2/0.71[GeV^2])^{-2}$ for all four: magnetic and electric for the proton, and magnetic and electric for the neutron³.

The most decisive studies of the partonic structure of nucleon could be performed when the dominant part of the wave function is a 3-quark Fock state. This requires large momentum transfer, $Q^2 > 1 \text{ GeV}^2$, when the contribution of the pion cloud is suppressed. The SLAC experimental data⁴ on the proton Dirac form factor F_1^p have been found to be in fair agreement with a scaling prediction⁵ based on perturbative QCD: $F_1^p \propto Q^{-4}$, where Q^2 is the negative four-momentum transfer squared.

The experimental results⁶ from Jefferson Laboratory (JLab) for the ratio of the proton Pauli form factor F_2^p and the Dirac form factor F_1^p have been found to be in disagreement with the scaling law $F_2^p/F_1^p \propto 1/Q^2$ suggested in reference⁵. A JLab high precision experiment made use of the double polarization method, which was first proposed in reference⁷. This method is less sensitive to the two-photon exchange contribution and, due to the interference nature of the double polarization asymmetry, has large sensitivity to the small electric form factor. The

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data for $\mu_p G_E^p / G_M^p$ shown in Fig. 1(left) present an amazing drop of G_E^p , which also means that F_1^p and $Q^2 \times F_2^p$ for the proton have different Q^2 dependencies.

The measurement of the proton to the neutron cross section ratio in the quasi-elastic knockout from the deuteron was used in JLab's precision measurement of the neutron magnetic form factor⁸. With the recent JLab experiment on the neutron electric form factor⁹, the data on all four nucleon form factors have become available in the Q^2 region of 3-quark dominance. Analysis of the flavor contributions to the nucleon form factors using the data was performed¹⁰. The flavor decomposition allowed us to make two new observations:

- The contributions of the **up** quarks and **down** quark to the magnetic and electric form factors of the proton all have different Q^2 dependencies.
- The contribution of the **down** quark to the F_1^p form factor at $Q^2=3.4 \text{ GeV}^2$ is three times less than the contribution of the **up** quarks (corrected for the number of quarks and their charge).

The second observation suggests that the probability of proton survival after the absorption of a massive virtual photon is much higher when the photon interacts with an **up** quark, which is doubly represented in the proton. This may be interpreted as an indication of an important role of the **up-up** correlation. At high Q^2 a correlation usually enhances the high momentum component and the interaction cross section. The relatively weak **down** quark contribution to the F_1^p indicates a suppression of the **up-down** correlation or a mutual cancellation of different types of **up-down** correlations. The QCD-based calculations of the nucleon form factors in the Dyson-Schwinger Equations approach¹¹ revealed a key role of the diquark in high Q^2 electron-nucleon elastic scattering.

2. Future experiments in Hall A with SBS

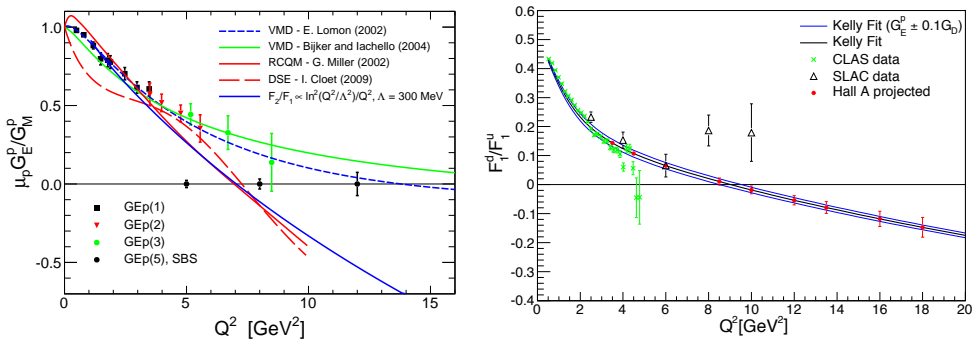


Fig. 1. Left: Existing data and projected data accuracy for the ratio of the $\mu_p G_E^p / G_M^p$. Right: Ratio of the **up** and **down** quark contributions to the proton form factor F_1^p .

Accurate measurement of the FFs at large Q^2 will be possible during the next few years at Jefferson Lab, where the 12-GeV energy upgrade is almost completed¹².

In 2007 we proposed a configuration of a large acceptance spectrometer at a small angle to the beam¹³. This large luminosity moderate acceptance spectrometer, SBS, became a key component of the form factor program in Hall A at JLab. The program includes the measurements of three ratios: the proton electric form factor to the proton magnetic form factor¹⁴, the neutron magnetic form factor to the proton magnetic form factor¹⁵, and the neutron electric form factor to the neutron magnetic form factor¹⁶. For absolute normalization of the form factor values, the precision measurement of the proton magnetic form factor will also be performed in Hall A¹⁷. A summary of experimental parameters is shown in Table 1.

Table 1. Future measurements of the FFs in Hall A at JLab (approved experiments). Projected range of Q^2 and accuracy relatively the dipole FF at maximum value of Q^2 .

Form factor	Reference	Q^2 range, GeV ²	$\Delta G/F_{Dipole}$ (stat/syst) at max Q^2
G_E^p	14	5-12	0.08 / 0.02
G_M^p	17	4.8-14.0	0.01 / 0.02
G_E^n	16	1.5-10.2	0.09 / 0.03
G_M^n	15	3.5-13.5	0.06 / 0.03

3. Flavor decomposition of the form factor F_1^p and GPDs at very large Q^2

At Q^2 above 10 GeV², measurement of the electric form factors, especially the G_E^n , becomes difficult. However, due to the large value of $Q^2/4M_N^2$, the F_1 could be obtained with a relatively small uncertainty just from the value of the magnetic form factor:

$$F_1 = (G_E + Q^2/4M_N^2 \times G_M)/(1 + Q^2/4M_N^2) \quad (1)$$

The flavor decomposition of F_1 also could be accomplished accurately. Fig. 1(right) shows projected data points and a systematic error corridor for assumed uncertainty in G_E^p of ± 0.1 . Here we used the Kelly fit form factors for illustration purposes. We would like to note that the ratio F_1^d/F_1^u could potentially cross the zero line, which would require a significant change of GPDs parametrization because the currently used form does not allow negative values of GPDs, see e.g. the reference¹⁸.

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